7.08

NOWCASTING THUNDERSTORMS WITH SIGOONS
A SIGNIFICANT WEATHER OBJECT ORIENTED NOWCASTING SYSTEM

Pascal Brovelli *, Stéphane Sénési , Etienne Arbogast, Philippe Cau,
Sandrine Cazabat, Michel Bouzom, Jérôme Reynaud
Météo-France,
Toulouse, France

1. INTRODUCTION

Nowcasting significant weather events cannot really be left entirely to automated systems, because the risks and consequences are too high to be ignored by human expertise. Nowcasting calls for automation, because of the refresh rates and spatial resolutions of observations at hand. This is why Météo-France is developing a hybrid system named SIGOONS (SIGnificant weather Object Oriented Nowcasting System), which allows for forecaster expertise incorporation while keeping some advantages of automated methods. This is based on an object-oriented approach.

At the moment, SIGOONS manages Significant Weather Objects (SWO) for thunderstorms and convection-prone areas. Eventually, it will manage fog areas, snow areas, icy weather areas, heavy rain systems and strong wind systems.

Thunderstorms are among the best candidate for the SIGOONS approach, because they are well defined meteorological objects with an almost unambiguous spatial envelope, which are well observed using satellite, radar and lightning data, and the basic linear extrapolation forecast method can be applicable within a half an hour or an hour of range.

The project is at a developmental stage. A first field experiment, covering all SIGOONS functions covering initialisation, production, checks and human expertise (but restricted to thunderstorm handling) was conducted during the summer of 2004. Three regional offices were involved.

* *Corresponding author address:* Pascal Brovelli, Météo-France, DPREVI/PI, 42 av G. Coriolis, 31057 Toulouse France; e-mail: Pascal.Brovelli@meteo.fr

The SIGOONS approach is presented in the following document, the results of this experiment and the necessary improvements. These concern firstly the CONO algorithm briefly presented in section 3, the human expertise in section 4, the assessment of the quality of the thunderstorm warnings produced automatically without human expertise in section 5.

2. SIGOONS APPROACH

The SIGOONS hybrid system is based on an object-oriented approach.

SWO are defined by a list of attributes that depend on their type and describe associated significant weather useful for clients. Attributes may have a non-deterministic formulation; for instance, SWO thunderstorm attributes like wind gust and rain rate have a non-deterministic formulation, which reflects both their variability over the area and the uncertainties in the observation or forecast. All SWO have a spatial envelope attribute.

SWO are managed as having a life-cycle (in other words, they have a time dimension). All attributes have a time evolution associated with it. Temporal bounds are set to H_0-2h and H_0+4h, where H_0 is the current time.

The basic principles are presented by the figure 1.

First step, SWO describing significant weather are diagnosed and created either based on the automated analysis of observational data like the CONO (COnvection Nowcasting Objects) for thunderstorms. It provides extensive and precise spatial coverage and initializes attributes. Automated methods provide a first guess of the future states for each SWO. Linear extrapolation is an obvious, basic forecast method. Persistence is the ultimate default method.

Second step, automatically diagnosed SWO or SWO's attributes (based on CONO or e.g. ground stations reports) are systematically checked against all analysis or forecast SWO having the same validity time. These checks ensure that the current forecast database is consistent with any significant observation. Discrepancies are as much as possible automatically processed, except if too strong, in which case they are brought to the attention of the forecaster on duty.

Third automated step, SIGOONS elaborate and disseminate products, which incorporate both up-to-date observation and forecaster expertise. Forecast production is heavily based on an automated process, which uses the SWO database and merges it with a customer requirements database for generating customer-specific warnings, forecast updates (amendments) and warning for the end of significant events. General products do also include updates of very short range forecast products with an automatically generated nowcasting module, either in voice or text form.

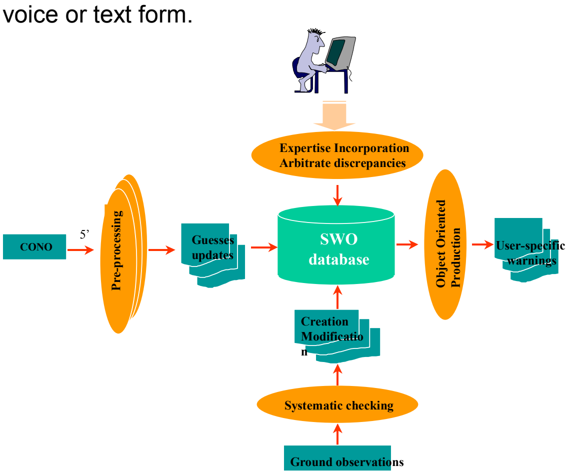

Figure 1: SIGOONS - basic principles

In the other hand, forecaster can incorporate expertise.

When a SWO presents a discrepancy after checks, the forecaster is prompted to choose either an automatically diagnosis or forecasted state. He can adjust the forecast of the SWO. The forecaster may also take the initiative in exerting his expertise about future evolution of the convective system(s) by acting on the forecast method and/or forecast states. In SIGOONS, the basic principle is to have the forecaster "in the loop" to give a more efficient role: he/she is provided with tools to monitor automated diagnostics and extrapolations, and to add value to convective objects such as indicating a decay/growth tendency and associated significant weather. The second main principle of the expertise is that the system must never be delayed or blocked by waiting for an input from the forecaster. SIGOONS must automatically process as best as possible. The forecaster can exert his expertise when he has enough time and the know-how to propose a better choice than the automatic process. At this first stage, we try to minimize the expertise workload. They are therefore provided with a friendly man-machine interface (MMI).

At the present time, SIGOONS manage thunderstorms. Because convection shows highly non-linear and quick evolution, its nowcasting faces typical challenges of the nowcasting activity; these includes : 1) getting a good and real-time diagnostic of thunderstorms development stage, dynamics, and organization using CONO 2) allowing a forecaster to exert his/her expertise about future evolution of the convective system(s), and 3) elaborate and disseminate user-specific products which incorporate both up-to-date observation and the forecaster's expertise.

The following sections describe improvements planned for SIGOONS for summer 2005, taking into account the results from the first field experiment for summer of 2004 which were restricted to thunderstorm handling.

3. OVERVIEW OF THE CONO ALGORITHM

The CONO (COnvection Nowcasting Objects) tools implement real-time object-oriented interpretation of radar data in order to automatically identify and track convective cells and/or convective systems. The CONO objects are an extension of the RDT objects.

While the RDT objects provide a characterization of convective clouds with satellite, the CONO objects will provide, for the same objects, a characterization of convective cells enhanced with the ARAMIS French radar network composite image. This should allow access to maximum and mean precipitation rates and precipitation fluxes observed below the detected convective cells.

CONO objects are available at a higher frequency than the RDT products: 5 minute frequency against 15 minutes for the RDT) in order to come as close as possible to real-time observation of convection and then to minimize the delay in warning customers.

3.1 *input data*

The French radar composite image is processed with 18 conventional radars, mostly C band, few elevations and 1km, 1dBZ, 5 min resolution. (see description of the French radar network and its development Tabary, 2005, same conference)

The structure of reflectivity can be complex. We try to match the convective system scale even convective systems are not necessarily made of connected cells: Before computing by the algorithm, we pre-process the composite image with smoothing (median filter order 3) and morphological « closing » (order 5) operations to merge cells by bridging gaps. (figure 2)

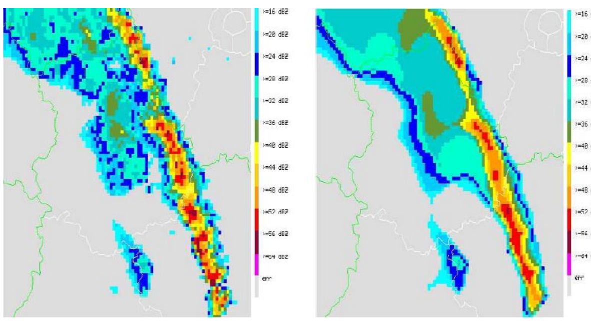

Figure 2: Pre-processing radar data. Case of 20030601: Convective system on northwest of France. Left before pre-procession, right after smoothing and morphological « closing » operations

3.2 *Detection*

The CONO detection method is based upon an adaptative reflectivity thresholding of radar data derived from the algorithms developed for the severe thunderstorms satellite nowcasting product RDT by Météo-France (Morel 2002). This radar scheme being developed by Météo-France in cooperation with MeteoSwiss, (see also Nowcasting thunderstorms in complex cases using radar data, Herring et al., 2005, same conference).

First, we detect the reflectivity threshold of each cell. Thus, a cell having its own reflectivity threshold between a minimum threshold dBmin and a maximum threshold dBmax represents a possible convective precipitation system. The rule used to select the reflectivity threshold is as follows: The reflectivity threshold used to detect a convective precipitation system is the lowest reflectivity threshold for which the difference between this threshold and the maximum reflectivity of the cell is smaller or equal to the convective precipitation system vertical extension Δ.

In order to detect systems with intense convective precipitation, only systems that show a reflectivity difference between their base and their top larger than a threshold ΔdB_{tower} (or ΔdB_{tower2} at the threshold dB_{min}) are detected. For instance, figure 3 shows a reflectivity vertical cross-section of an idealized convective precipitation system. In this figure, cells 1 and 2+3 are detected. Convective system 2 is gathering with 3 because, its vertical extension is too small. In order to detect only but all significant convective systems we add two new rules. First, at the minimum threshold dB_{min}, all system with a vertical extension greater than ΔdB_{tower2}, (threshold lower than ΔdB_{tower}) are selected: In figure3, cell 4 is also detected. Second, all cells with a maximum reflectivity greater than $dB_{maxdetect}$ are selected. This last rule improves also the gathering of close maximums together. Red lines represent the detection threshold of selected cells.

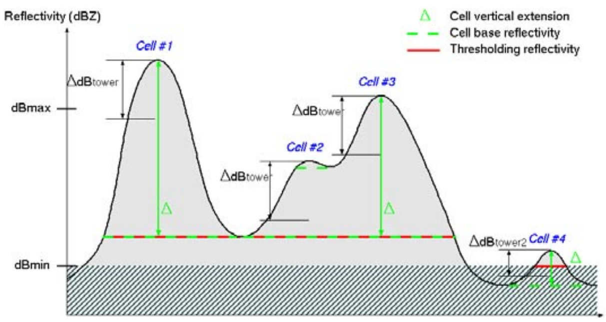

Figure 3 : Diagram illustrating the principle of the CONO detection algorithm.

After tuning, the values for SIGOONS experiment for summer 2005 are: dB_{min}=35dBz, dB_{max}=45dBz, ΔdB_{tower}=7dBz, ΔdB_{tower2}=5dBz and $dB_{maxdetect}$=45dBz .

3.3 *Tracking*

The goal of the tracking algorithm is to link objects detected in two consecutive radar composite images and corresponding to the same convective system. Once the tracking is done, it is then possible to derive the trajectory (i.e. the time series of objects) of systems.

The CONO tracking algorithm principle is the same as RDT tracking fully presented in Morel et al (2002). It is based on the computation of the geographical overlapping between a cell detected in the present image and cells detected in the previous image using an estimated speed of cells. It handles complex cases like merges and splits of cells. The differences concern the cell speed estimation.

One of the conclusions of the experiment for summer 2004 is that CONO are fine in flat regions, but improvements are needed for the tracking of complex systems like re-generating convective systems. The tuning take into account the initialisation of speed using a best synergy between centroïd tracking and cross correlation.

In case of significant cell area variation due to the large spatial and temporal dynamics of the radar reflectivity field or the change of threshold detection cell between two consecutive images the reliability of the cell's displacement velocity calculated based on the displacement of the cell gravity centre is mediocre.

On the other hand, when speed initialisation uses systematically cross correlation, the tracking and the linear extrapolation forecast are on the whole improved except for stationary regenerated convective systems such as systems observed on the southern flank of the Alps in Mediterranean flash flood cases. In these cases, the scheme tracking is able to describe and track at the cell scale rather than at the system scale therefore the linear extrapolation moves these systems too north and too fast.

The last assessments particularly on stationary convective systems show that the best results on tracking and linear extrapolation forecast are obtained with a speed initialisation tuning which blend displacement of the cell gravity centre and cross correlation as follow :

- cross correlation when the area variation of a cell is too high. The area variation thresholds used are 10km² in absolute and 20% in relative.
- displacement of the cell gravity centre in the other case. We use gravity centre balanced by reflectivity field under the cell

About fifty percent speeds are calculated by the displacement of the cell gravity centre.

Finally, the calculated speed is balanced with the previous cell speed (one-third of the new speed and two-third of the previous) to have smooth variation in direction and speed.

3.4 *Discrimination of convective systems*

Lightning data helps to characterize the convective SWO between heavy showers and thunderstorms, through a space-time integration of flashes counts over their trajectories.

3.5 *Other automated processing*

Monitoring system permanently checks the consistency between the corresponding nowcast object-oriented database with new CONO guess or new (sparsed) observations like wind gust reports, and warns the forecaster as necessary, in a user-friendly way.

Systematic checking assures consistency over all available observations.

SWO keeps all the ground observations reports collected below a position of its trajectory.

The CONO objects feed the SIGOONS objects database with SWO thunderstorm guess. CONO initialise several attributes: of course spatial envelope and displacement speed, but also rain rate, hail risk and lightning activity.

4. HUMAN EXPERTISE

4.1 *Purposes*

SIGOONS is a hybrid system. It allows forecasters to use their expertise on diagnosed objects of various categories. The first category implemented being the one of convective objects. The forecaster “in the loop” is provided with tools to monitor automated diagnostics and extrapolations, and to add value to convective objects such as :

- Set associated significant weather attributes for objects, or monitor their automated initialisations: wind gusts, hail risk, rain accumulation,
- Indicating a decay/growth tendency and associated significant weather
- Set non-linear tendencies on location, duration, attributes …
- Create objects for convective phenomena missed or not anticipated by the CONO
- Merge CONO objects of similar behaviour when necessary

4.2 *Experiments*

These tools are made available to the forecaster on their Synergy workstation, using specifically designed functionalities. Since the summer of 2004, we have organized real-time experiments and studies on archived cases using Man-Machine Interface prototype. Ergonomists (Chabaud et al., 2005, same conference) have helped us to have a better understanding of how the forecasters exert their know-how and in this way we are able to specify the methods of works and design the tools.

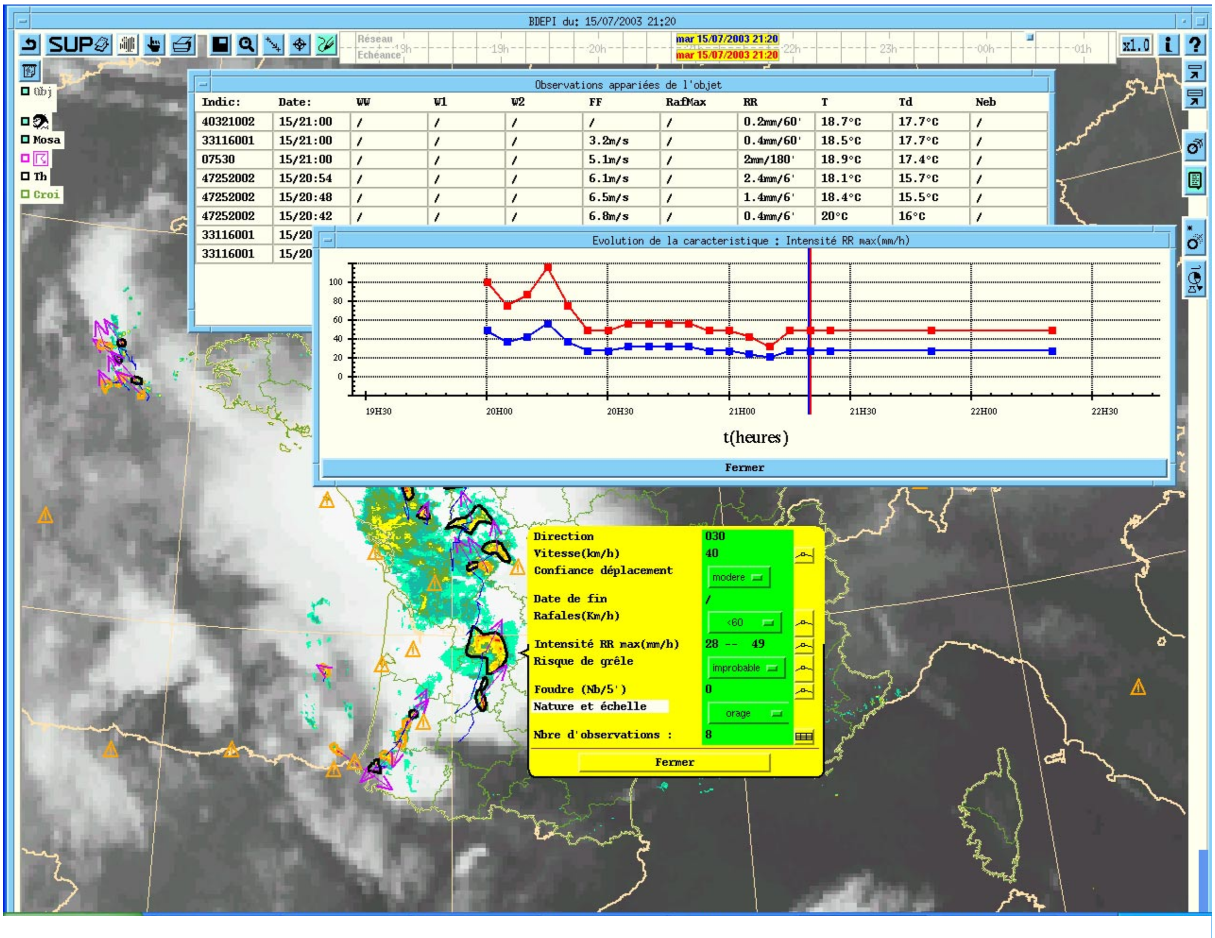

Figure 4 : SIGOONS Man-Machine Interface on Synergie workstation. Thunderstorms on the south-west of France the 15th July 2003. SWO thunderstorms envelopes are display with a dark line under infrared satellite data and composite radar data. Near west of Pyrenees, orange lines represent SWO with mismatch and orange triangles point to significant observations not paired to a SWO. The “yellow” window describes characteristics of the pointed SWO. The “white” window with two curves describes the rain rate evolution (max and main value diagnose with radar) since the beginning of the tracking and forecast by persistence. In the second “white” window behind, the table presents ground observations collected over the SWO trajectory.

After these experiments, the main positive feedback has been that forecasters feel that the object oriented representation merging spatial envelope, associated significant weather attributes and collected observations data is clearer. They feel useful in visualizing the SWO's states automatically calculated within a half an hour or an hour of range.

On the other hand, forecasters are anxious about the workload and their ability to exert expertise when SWO are so frequently updated (at least every five minutes). During the summer of 2004, interaction was quite heavy, but it will be made easier by various tunings.

Therefore, SIGOONS is designed to, whenever possible, automatically diagnose for each attribute, values resulting from various sources of observation such as radar, ground stations or default values. Finally, implemented rules choose automatically the best one. Concerning thunderstorms, rain rate and hail risk initialisation use mostly radar data, lightning flashes describe lightning activity of convective cells. Without Doppler radar network, the ground automatic station network is most often not dense enough to observe wind gust under thunderstorms.

The forecaster can also initialise attributes or choose between different automated diagnostic values. In this case rules of "expertise slip " allow keeping this expertise on the new diagnosed SWO states as long as the expert choice is consistent with new observation data.

SIGOONS should favour automatismed processing during the first hour and concentrate the human expertise input between the first and fourth hours to forecast convection using SWO relevant to larger spatio-temporal scale like thunderstorm systems or convection-prone areas better suited to MM interaction. The experiment for summer 2005 should help us to define the use of these larger objects.

The lastest results on case studies show that the expertise is mostly qualitative like " wind gusts stronger near the coast " " thunderstorm most frequent on the relief" or "severe thunderstorm locally". We will also have to compute this qualitative expert formulation in non-deterministic formulation and use it in the warning production.

5. ASSESSMENT OF THE QUALITY OF THE THUNDERSTORM WARNINGS

Since the summer of 2004, a production system has made use of this nowcast object-oriented database in order to derive automatically targeted products; among user- and site-specific warnings, tuned depending on the requirements of the user to the probability of occurrence of thunderstorm. Time-consistency of warnings is ensured and the warning end is forecasted. Warnings are updated on "canton" of about 100km² area, every quarter of an hour. About 3700 calls for, all over the French territory, were specified for this assessment. Another product for the general public is a text bulletin describing the next two hours, the occurrence and evolution of thunderstorms for regions over an area of 6000 km2 large.

Meteorologists have assessed subjectively and in real-time these automatically computed products during summer and autumn. They have only worked on a few selected warnings in their suitability.

Automated products are much promising. The products are correct and faithfully translate the nowcast database contents. The warning site is correct and seems to be useful for potential clients.

Improvements are needed for describing associated significant weather particularly rain accumulation. Time consistency and stability of warnings must also be improved because the warning end is forecasted too early and a new warning is triggered of again. Products have to be update more frequently (every 5 minutes like SWO)

The following example of the 11 August 2004 tornado case, two hours ahead of the touch down illustrates the good quality (good localization on Quiberon two hours ahead) and the default (rain accumulation underestimated and no wind gust forecast) of the warning product:

« *For the Morbihan departement, in the next hour. Thunderstorms are partially affecting the following*

« cantons »: PLOEMEUR, PLOERMEL, JOSSELIN with rainfall accumulation around 10 mm. They move to the north-east at 40 km/h. The following « cantons » will be touched within one or two hours: QUIBERON, AURAY, PORT-LOUIS »

6. OUTLOOK

The 2004 experiment results are encouraging, even if some improvements are necessary.

During the winter, SIGOONS software had been re-designed to be more generic, in order to prepare the management of new SWO and to improve performance.

In the short term - this year - two actions are planed concerning expertise. First, SWO display tools will be made available to all regional offices forecaster on the operational Synergy workstation so that they can get used to these new tools and the object-oriented approach. This experiment doesn't assess expert input. Second, an experiment on case studies goes on to tune expertise to reduce workload and by using SWO larger spatio-temporal scale. We are going to also improve the uncertainty on phenomena location and intensity management.

Also underway is the assessment of the quality of the thunderstorm warnings produced automatically without human expertise in terms of FAR and PoD. We will improve warnings, smooth amendments, stability and intensity. We will also test with a few volunteer professional clients a "warning pack" which group together nowcast warnings and short range forecasts. On the other hand we will design a general public warning product distributed by phone.

In the medium term - next year – we should specify objective guidance on assessing/forecasting associated significant weather like rain accumulation, thunderstorm intensity using helicity or wind gust using DCAPE… SIGOONS should benefit from CONO's improvement with the new scheme designed to automatically shift from satellite tracking to radar tracking depending on the cell development stage. Concerning expertise, the results of the current ergonomic study should help us to be able to specify the expertise methods on SWO thunderstorm and so expand in one or two regional office(s) the first SIGOONS version with expert contribution. We will have to specify the co-operative expertise rules necessary for expanding SIGOONS in the seven regional offices and especially how to exert an expertise on a convective system that crosses several meteorological regions.

Automatic production will also be improved; a graphic and a general public product are planned.

In the long term, SIGOONS will be able to manage other significant weather first fog areas but also heavy rain systems, strong wind systems or snow areas…

6. REFERENCES

Alessandro M. Hering, Stéphane Sénési, Paolo Ambrosetti, and Isabelle Bernard-Bouissières, 2005 : Nowcasting thunderstorms in complex cases using radar data. In this issue.

C. Chabaud , S. Cazabat, 2005 Ergonomical design of a tool dedicated to nowcasting forecast. In this issue.

P. Tabary, 2005. The new French operational conventional radar products. In this issue.

Morel, C., S. Sénési, and F. Autones, 2002: Building upon SAF-NWC products: Use of the Rapid Developing Thunderstorms (RDT) product in Météo-France nowcasting tools. Proceedings, *The 2002 Meteorological Satellite Data Users' Conference,* Eumetsat and Met Eirean, Dublin, Ireland, 248-255.

MOREL, C., SENESI, S., AUTONES, F. and L. LABATUT, 2000 : The Rapid Developing Thunderstorms (RDT) Product of the Nowcasting SAF. Prototyping activities and quality assessment using GOES images. *Proc. The 2000 Meteorological Satellite Data Users' Conference*, pp 698-705, Eumetsat and CNR, Bologne, Italie.